

CH Cavity Development and Perspectives for a New GSI Proton Linac

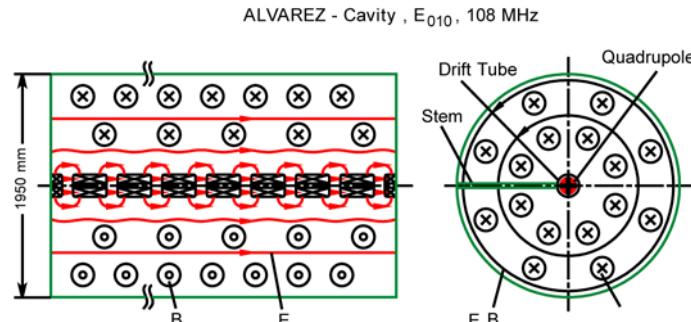
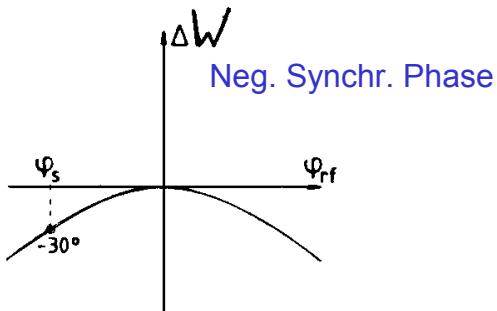
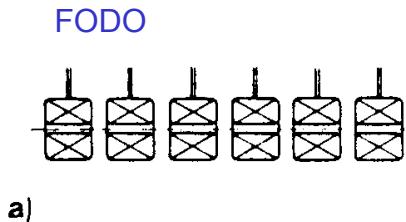
R.Tiede

HIPPI WP2 meeting,
Grenoble, 4/5 may 2004

- General information on the CH cavity and the KONUS beam dynamics
- CH-DTL cavity design status
- GSI Proton Linac beam dynamics design status
- Outlook / Conclusions

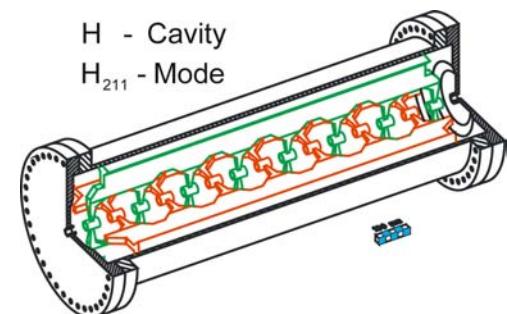
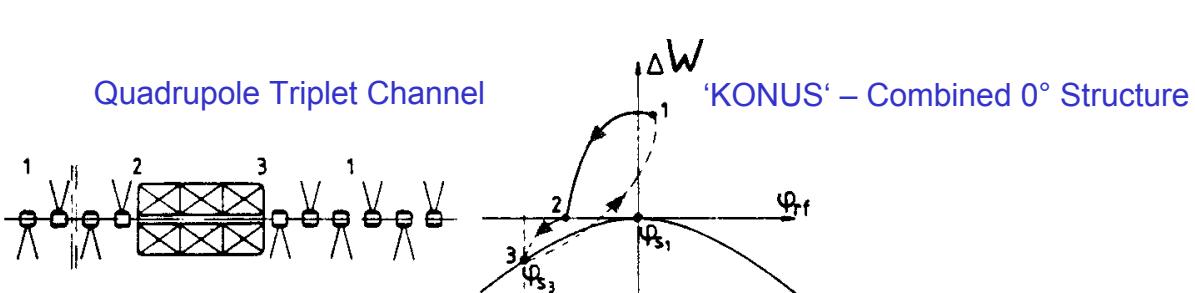
Comparison FODO / KONUS

- “Standard” linac design (up to ≈ 100 MeV) : Alvarez DTL + FODO beam dynamics.
Max. achievable accel. gradients limited to ≤ 2 MV/m.



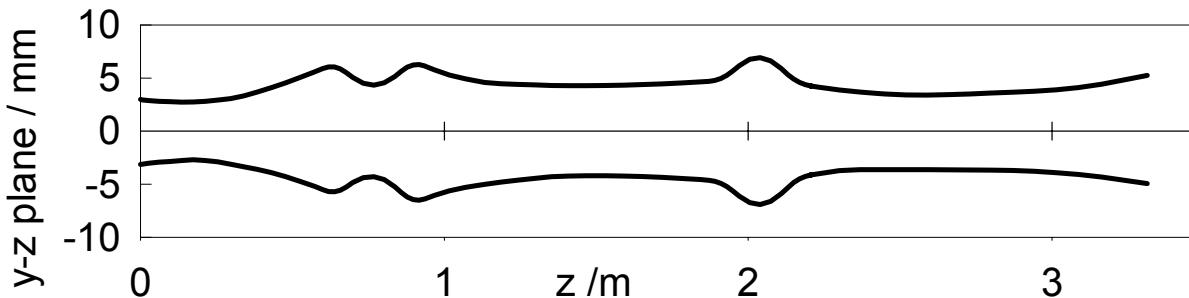
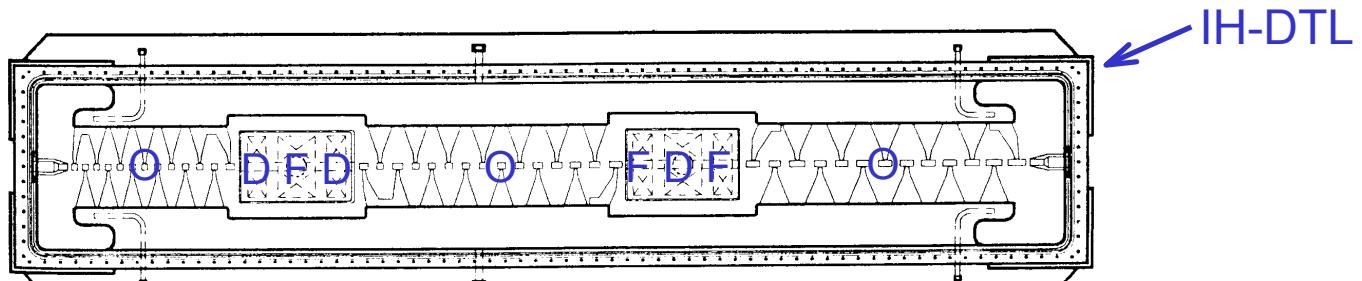
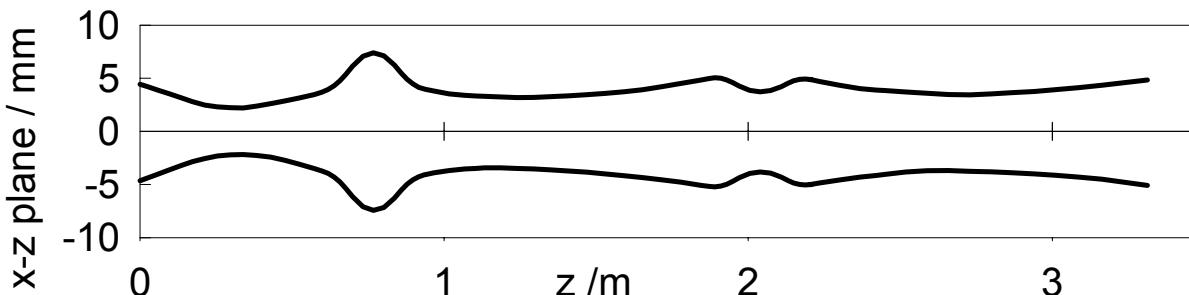
Alternative :

- Crossbar H-Type (CH) DTL and KONUS beam dynamics (“Kombinierte Null Grad Struktur” – Combined 0° Structure ; also known as “separated function linac”).
 - High accel. gradients (≤ 6 MV/m) due to high shunt impedance of CH-DTL and KONUS dynamics (“slim” drift tubes without integrated quadrupole lenses).
 - Simplified construction, maintenance and reduced number of components.



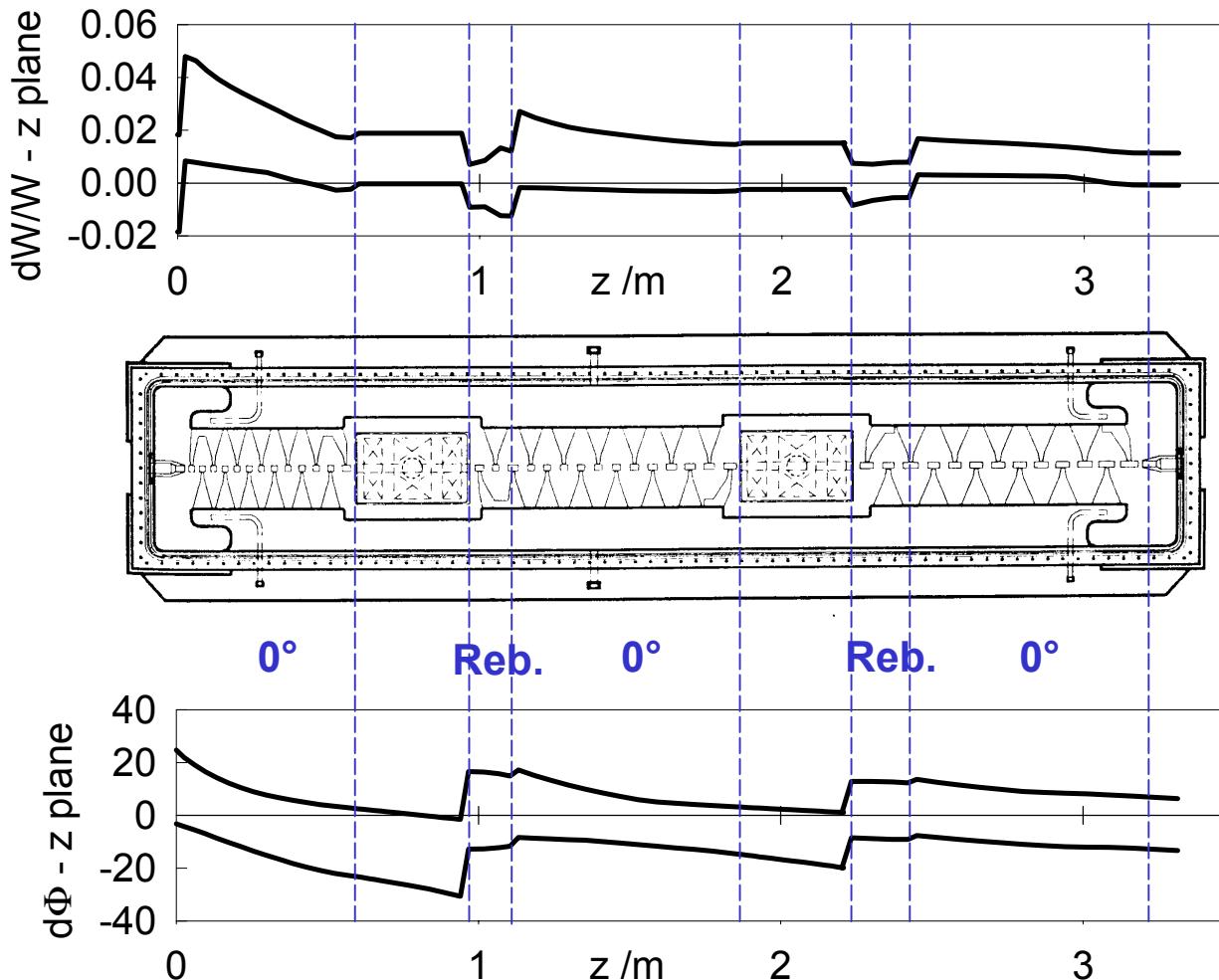
KONUS Beam Dynamics – Transverse Motion (Example : GSI - HLI)

Quadrupole Triplet Channel :



KONUS Beam Dynamics – Longitudinal Motion (Example : GSI - HLI)

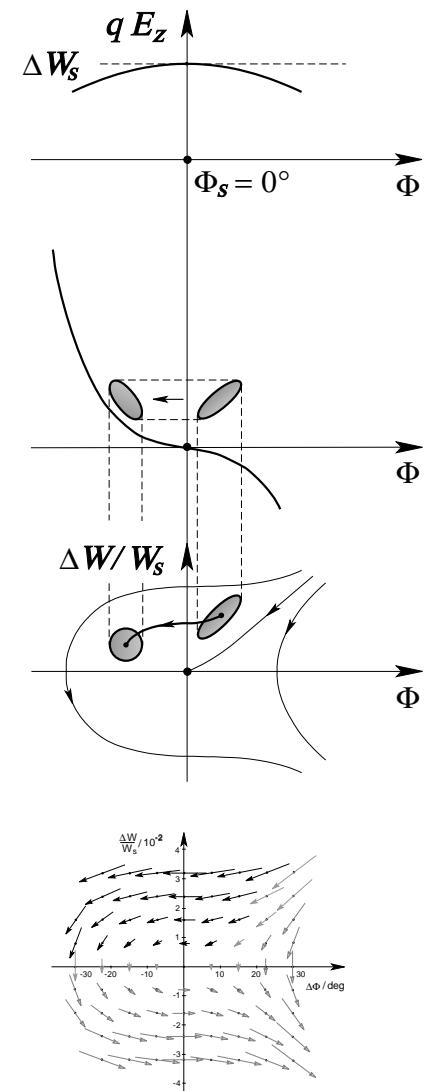
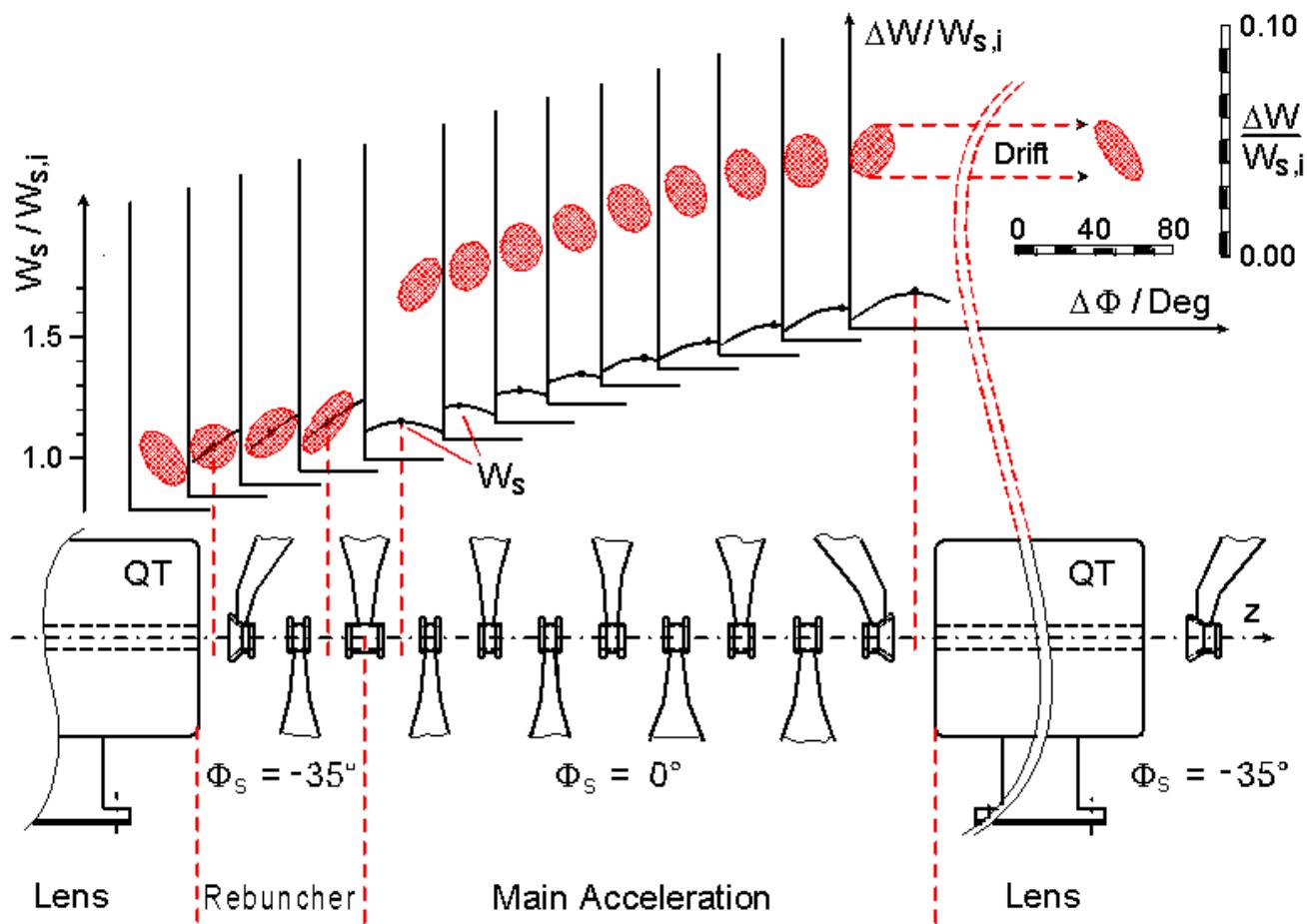
Combined 0° Structure :

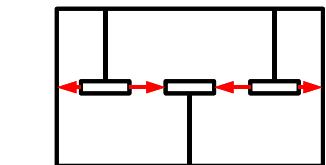
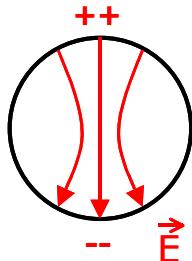
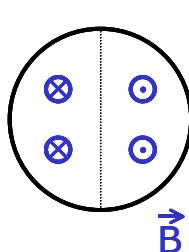
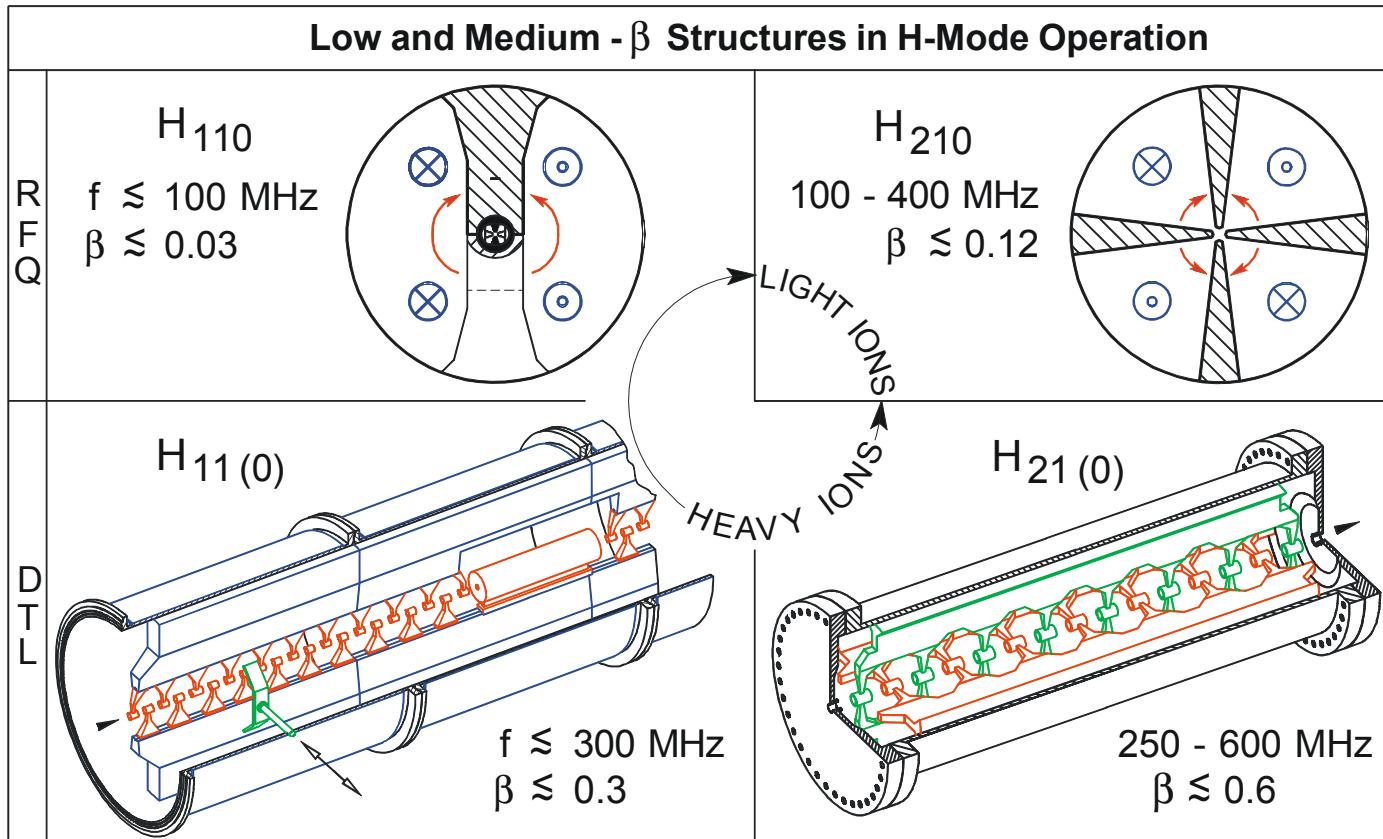


KONUS Beam Dynamics – Longitudinal Motion

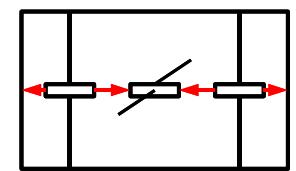
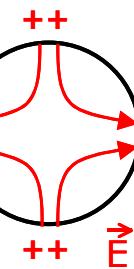
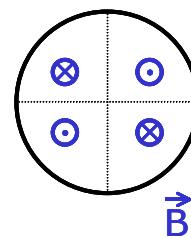
(Example : GSI - HSI)

GSI-HSI ; IH 1 tank, 2nd section



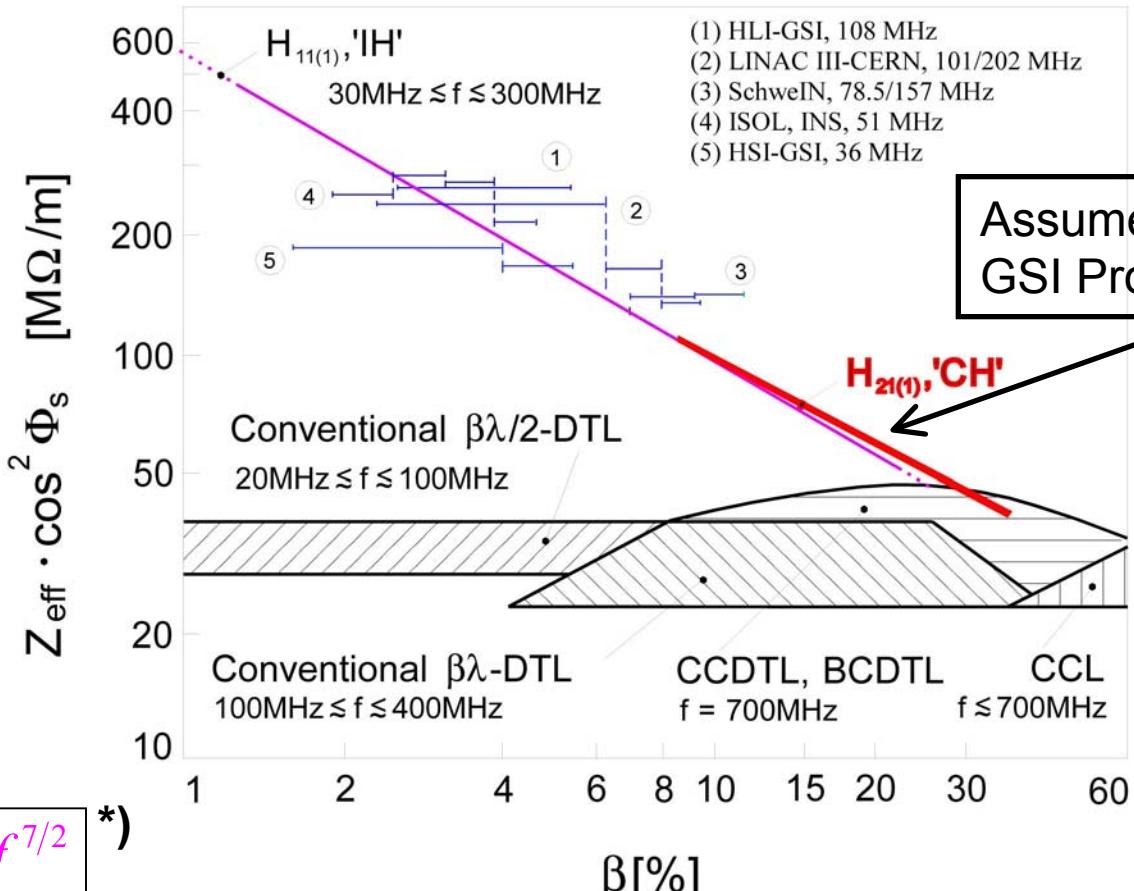
H-mode Structure Family

Interdigital H-Mode (IH)



Crossbar H-Mode (CH)

Comparison of Shunt Impedance Values



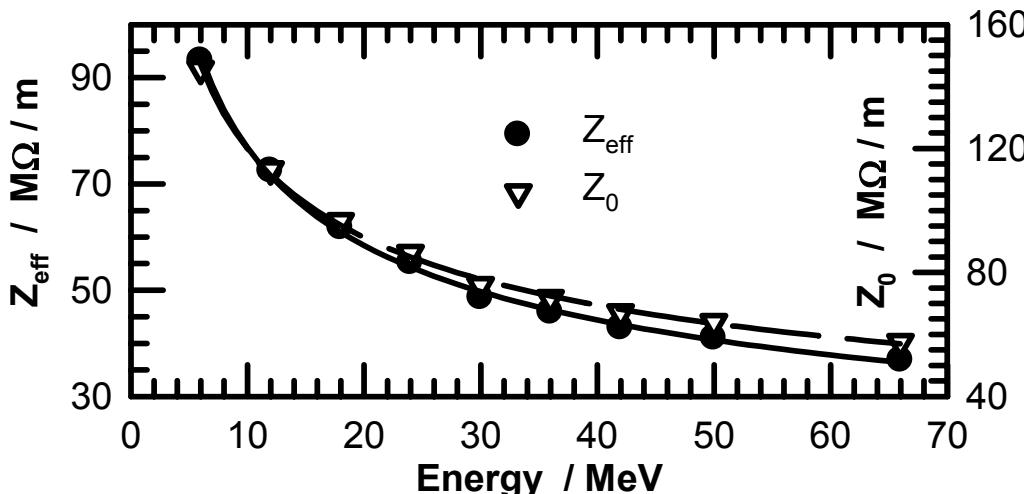
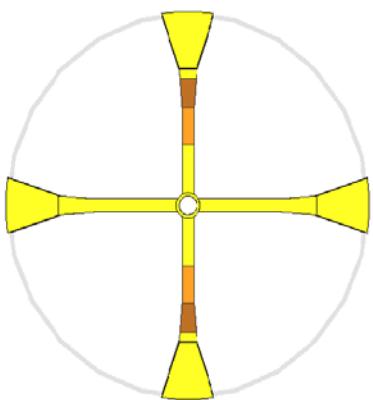
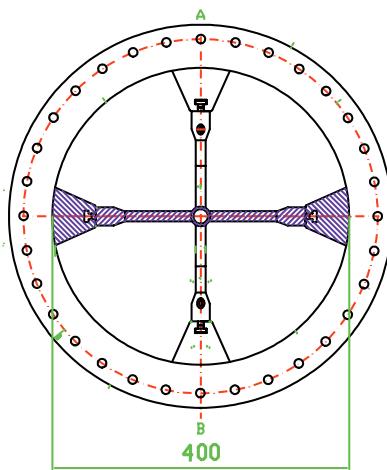
*) E.Nolte et al. – “The Munich linear heavy ion postaccelerator”, NIM 158 (1979), p. 311 - 324

CH-DTL cavity design status

ID	Task Name	Deliverables	2004												2005												
			11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
1	WP2: NORMAL CONDUCTING STRUCTURES																										
7	H-mode Drift Tube Linac																										
8	RF model CH tank1 RF design																			IAP-FU							
9	RF cold model design & construction																								IAP-FU		
10	RF model construction																										
11	Beam dynamics design CH tank1	06/05 Design report																		IAP-FU							

- Cavity cross section optimization based on single cells performed (ID = 8).
- First results on Microwave Studio™ design of multigap resonators (ID = 8).
- Design and fabrication study will be worked out together with an industrial manufacturer (bid received) ; (ID = 8).
- A mechanical stress study (elastic and inelastic) will be performed on a drift tube and supporting stem sample device (PhD thesis) ; (ID = 8).
- First drawings for a cold model cavity created, but final geometry will depend on the results from beam dynamics calculations and the Microvawe Studio optimization.
Components of the existing s.c. cavity cold model could be used (ID = 9).
- All data needed for the design of the CH-DTL tank 1 prototype power cavity (scheduled for 06.2006) will be available around 09.2004 (ID = 10).

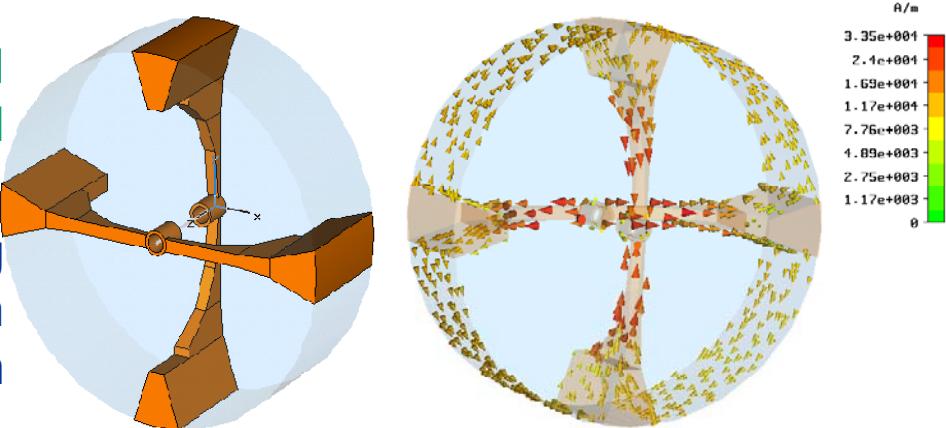
Cavity design with Microwave Studio™ for shunt impedance optimization



- Cavity cross section optimisation based on single cells performed.

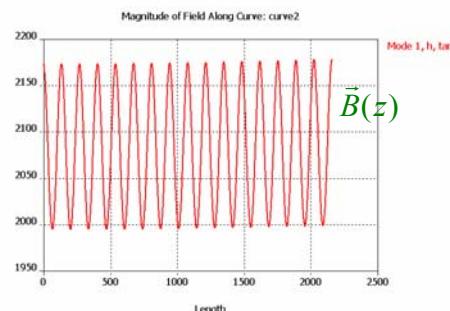
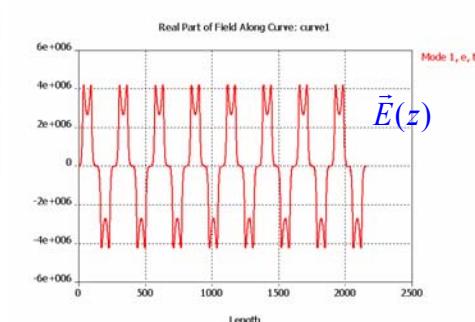
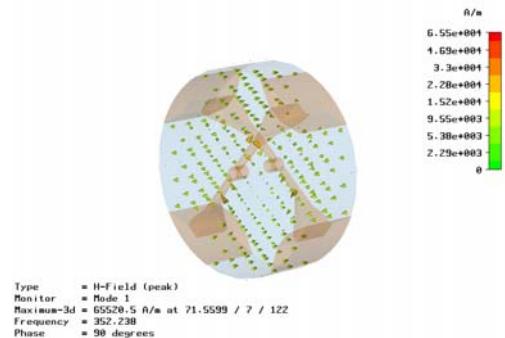
Results are applied to the numerical design of complete CH resonators and on cold model cavity design.

- Effective shunt impedances ranging from $100 \text{ M}\Omega/\text{m}$ at injection energy down to $35 \text{ M}\Omega/\text{m}$ at the linac exit seem feasible.

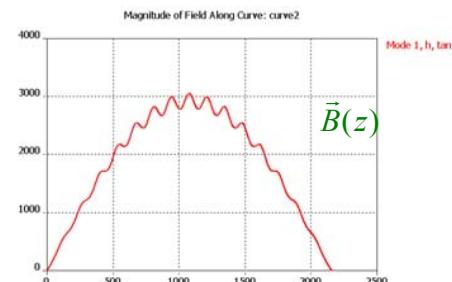
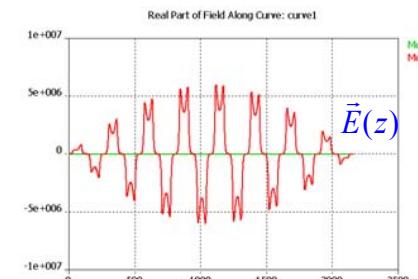
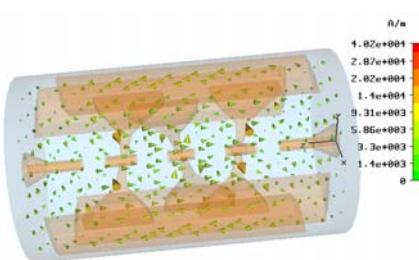


First Results on Numerical Design of Multigap Resonators

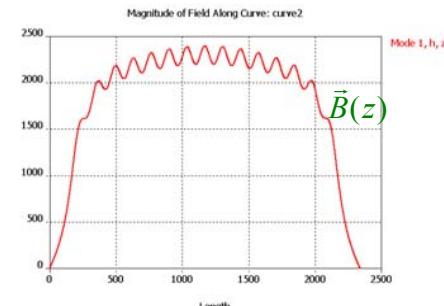
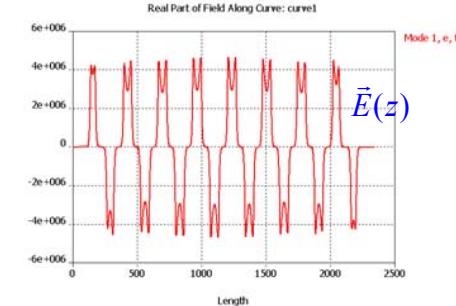
Electric and magnetic field for single cell cavity with magnetic boundary conditions :



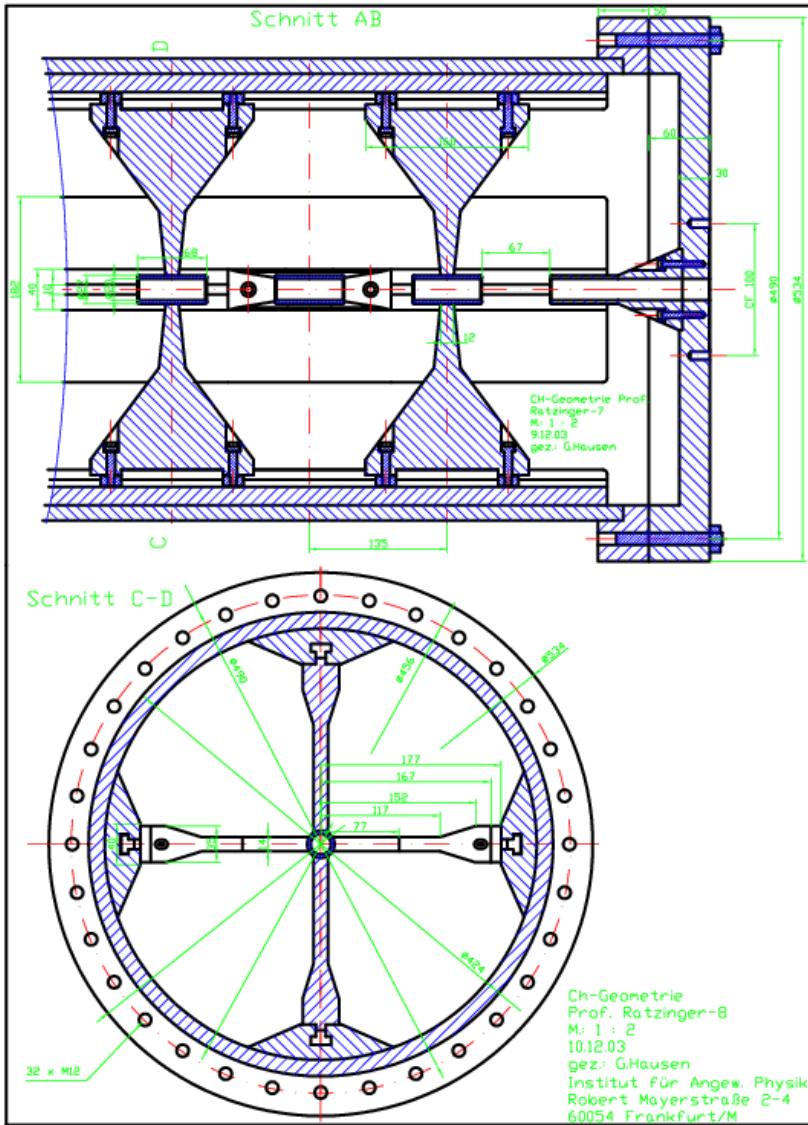
Multicell cavity with pure TE211 mode components (end plates are ideal magnetic conductors) :



Multicell cavity after volume tuning of tank end regions :

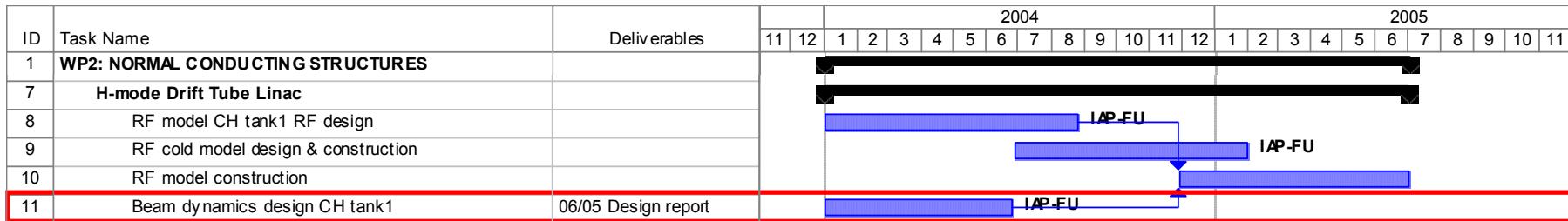


CH-Cavity Design Status : Future Plans



- A design and fabrication study will be worked out together with an industrial manufacturer (first drawings available).
- A mechanical stress study (elastic and inelastic) will be performed on a drift tube and supporting stem sample device (PhD thesis).
- To build up the 352 MHz, 1:1 scale "cold" model, components of the existing (350 MHz) s.c. model cavity could be reused :



GSI Proton Linac beam dynamics design status

- The design of a 70 mA, 4-70 MeV scheme was completed and presented at GSI Future Facility Workshop in Oct. 2003, using LORASR generated input distributions.
- Based on this, the influence of different RFQ output particle distributions (absolute emittance values) on the overall CH-DTL beam dynamics results was investigated, in order to define the ideal beam requirements out of the RFQ.
- The RFQ – CH-DTL transition energy was defined at 3 MeV.
- Two MEBT options are investigated in parallel : one standard rebuncher and external quadrupole lens solution, as well as a direct RFQ-CH-DTL coupling.
- The beam dynamics design will be finished mid 2004.

GSI Proton Linac Parameters

(published at Oct. 2003 workshop)

RFQ exit (courtesy of L.Groening : UNILAC note, 22.09.2003) :

RFQ exit		
E [MeV]	I_p [mA]	$\epsilon_{t,n}/\epsilon_l$ [μm]/[deg MeV]
2.5–7	≥ 70 *)	$\leq 1.4/\leq 1.0$

*) = 90 (“safety margin”)

Linac exit :

Proton Linac	
Beam energy	70 MeV
Macro pulse current	70 mA
Macro pulse length	0.1 ms
Transverse beam emittance	≤ 7 mm mrad
Longitudinal emittance	17 keV ns
Bunch frequency	352 MHz

$$\beta = 0.3661$$

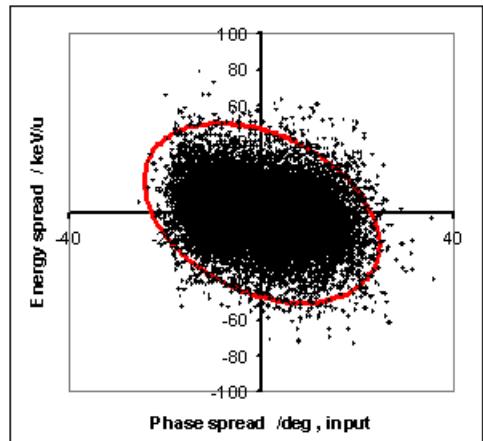
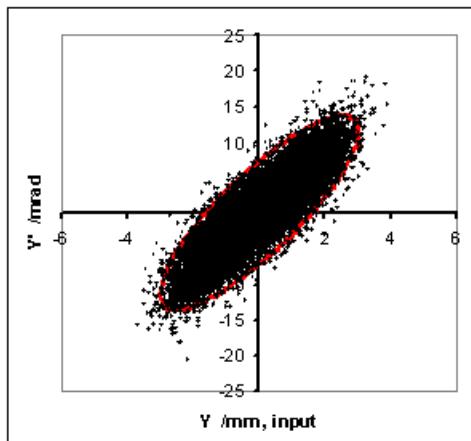
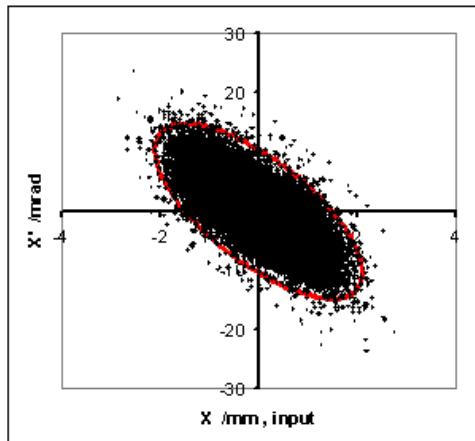
$$\epsilon_n = 2.56 \text{ mm mrad}$$

$$2.156 \text{ MeV deg}$$



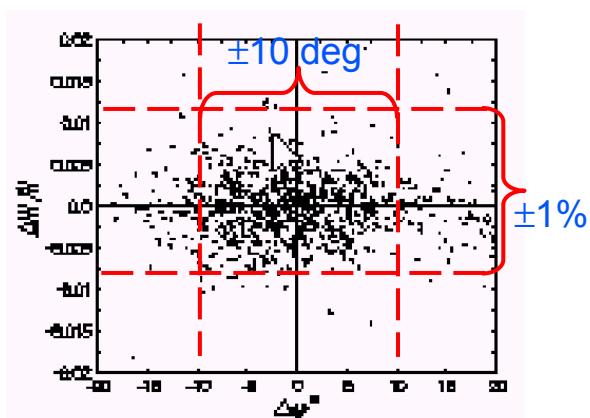
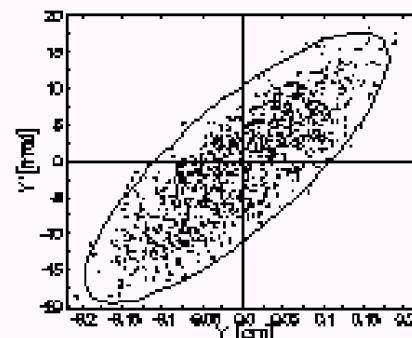
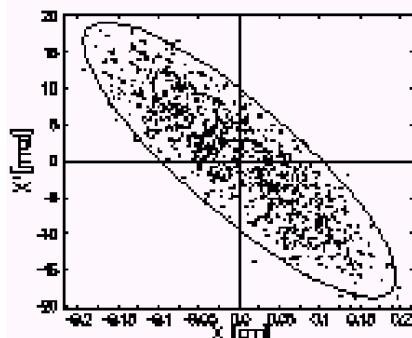
Available RFQ Exit Data

IPHI RFQ Design (70 mA, 98% ellipses) :

 $\delta_n / \text{mm mrad} = 1.76328$ $\delta_n / \text{mm mrad} = 1.75658$ $\delta / \text{keV/u*ns} = 9.01645 = 1.14 \text{ MeV deg}$ 

Design IAP- Prof. Schempp (70 mA) :

RFQ, F=350 MHZ, U=68KV
NCELL=303, NPOINT=650, NTOTAL=1000, Iin=70mA

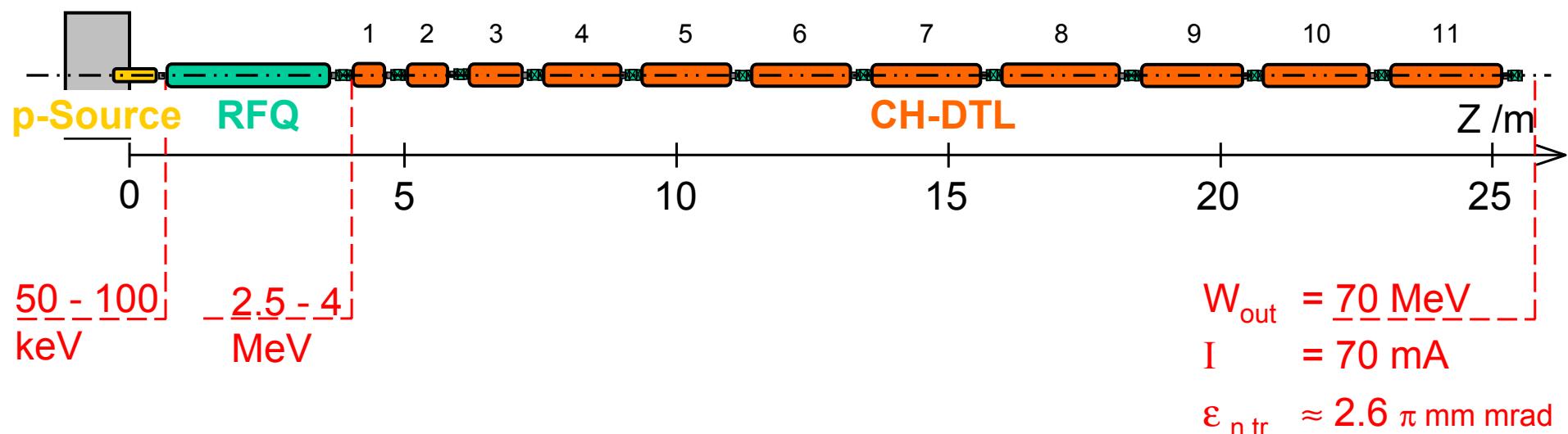


< 1.5 mm mrad

Proposed GSI Proton Linac – CH DTL Section

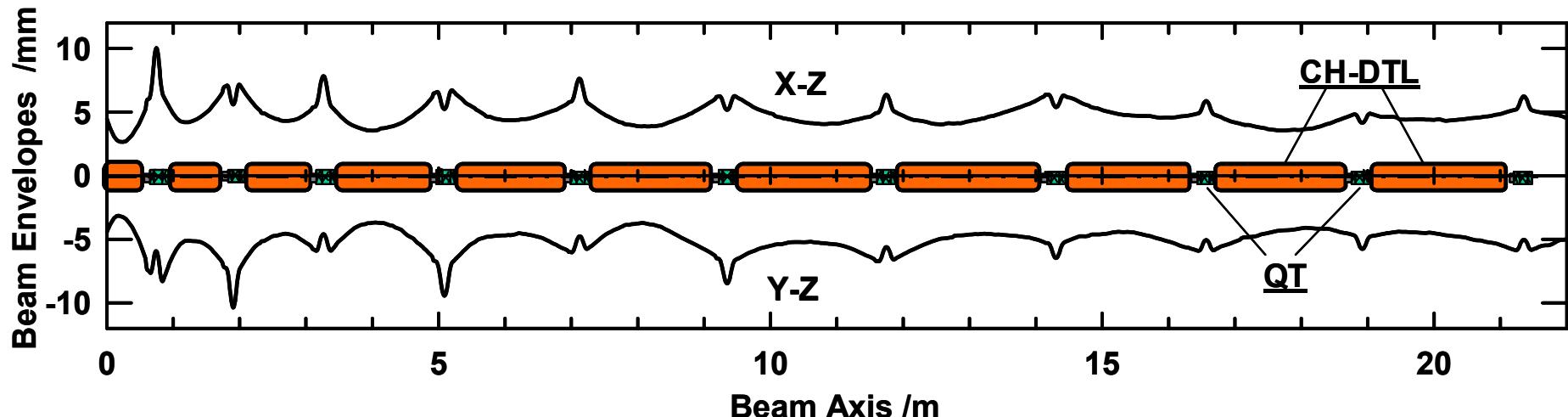
(scheme 4-70 MeV presented at GSI Future Workshop, Oct. 2003,
using LORASR generated input distributions)

	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6	Tank 7	Tank 8	Tank 9	Tank 10	Tank 11
L / m	0.6	0.8	1.0	1.4	1.6	1.8	2.0	2.2	1.9	2.0	2.0
Gap no.	12	14	14	17	17	17	17	17	14	14	14
W _{gain} / MeV	3.4	5.0	4.6	7.4	7.1	7.2	7.4	7.3	6.1	6.1	5.4
U _{grad} / MV/m	5.9	6.3	4.7	5.2	4.3	3.9	3.7	3.4	3.3	3.1	2.7
Z _{eff} / MΩ/m	75.9	64.5	57.8	51.9	47.6	44.5	42.0	40.0	38.5	37.4	36.4
P _{loss} / kW	263	485	374	743	646	637	652	616	519	508	395
P _{beam} / kW	238	350	322	518	497	504	518	511	427	427	378
P _{tot} / kW	501	835	696	1261	1143	1141	1170	1127	946	935	773



DTL Beam Dynamics Design (4-70 MeV) based on the IPHI RFQ Output Distributions

Design presented at GSI Future Workshop, Oct. 2003, using LORASR generated input distributions :



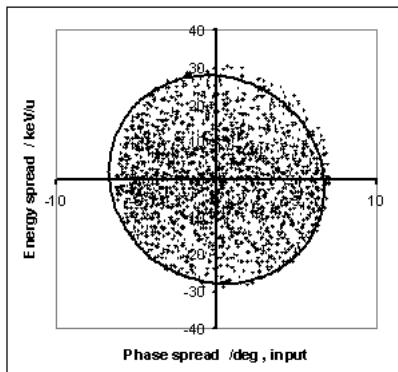
Case comparison :

- **Case 1 :** IPHI distribution. 2-dim. clusters mapped to “matched” beam conditions at the CH-DTL entrance.
Only **particles** with coordinates inside initial design ellipses are selected.
- **Case 2 :** As case 1, but using **all** IPHI RFQ output particles (19888).

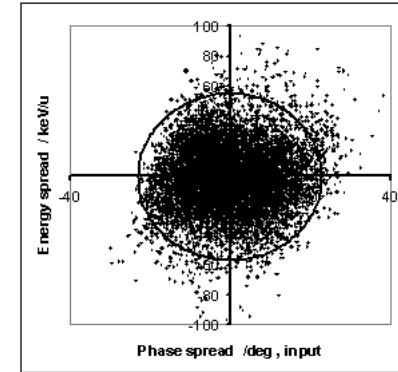
Comparison of Results in Long. Plane (95 % Ellipses)

Design : < 1.0 MeV deg

$$\delta / \text{keV/u} \cdot \text{ns} = 1.47275 = 0.19 \text{ MeV deg}$$



$$\delta / \text{keV/u} \cdot \text{ns} = 10.0681 = 1.3 \text{ MeV deg}$$

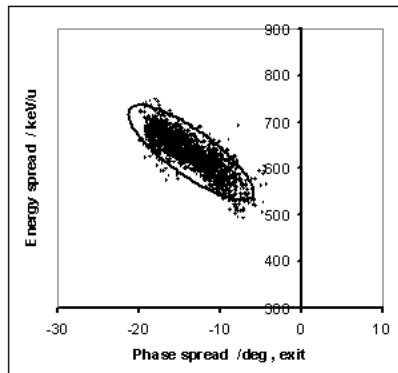


Case 1, input
IPHI distribution,
selected particles.

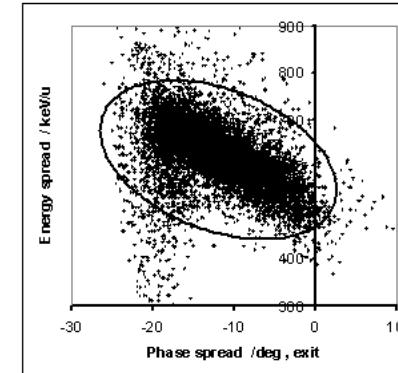
Case 2, input
IPHI distribution,
all particles.

Design : < 17 keV ns

$$\delta / \text{keV/u} \cdot \text{ns} = 3.53102$$



$$\delta / \text{keV/u} \cdot \text{ns} = 18.1807$$



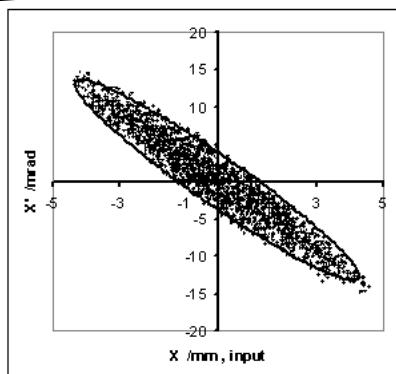
Case 1, exit
IPHI distribution,
selected particles.

Case 2, exit
IPHI distribution,
all particles.

Comparison of Results in XX' Plane (95 % Ellipses)

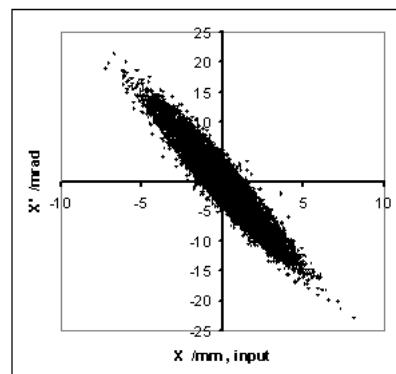
Design : < 1.4 mm mrad

$$\varepsilon_n / \text{mm mrad} = 1.52184$$



Case 1, input
IPHI distribution,
selected particles.

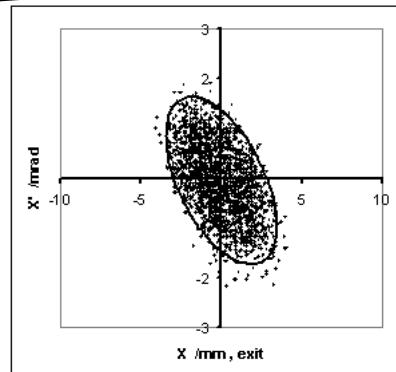
$$\varepsilon_n / \text{mm mrad} = 1.76091$$



Case 2, input
IPHI distribution,
all particles.

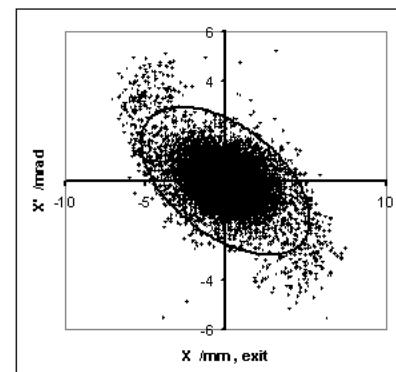
Design : < 2.5 mm mrad

$$\varepsilon_n / \text{mm mrad} = 1.93023$$



Case 1, exit
IPHI distribution,
selected particles.

$$\varepsilon_n / \text{mm mrad} = 5.31571$$



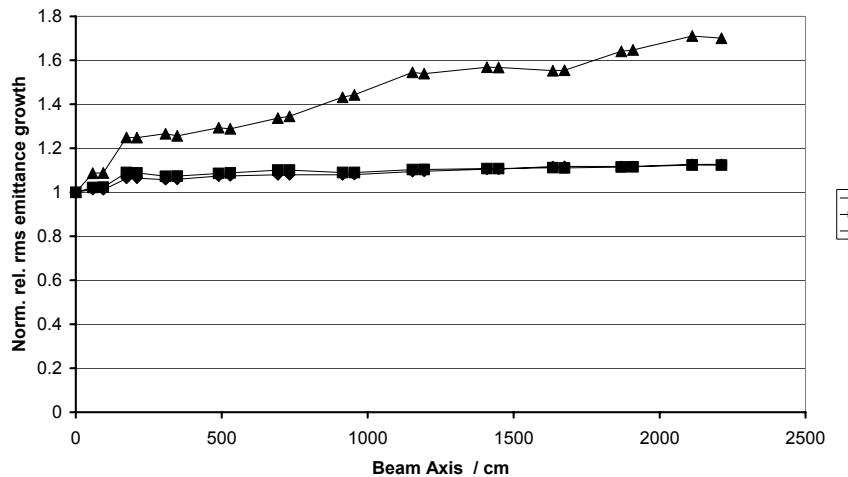
Case 2, exit
IPHI distribution,
all particles.

Larger longitudinal bunch shape resulted into **transverse halo !**
(due to achromaticity effects)

Comparison of rms Emittance Growth

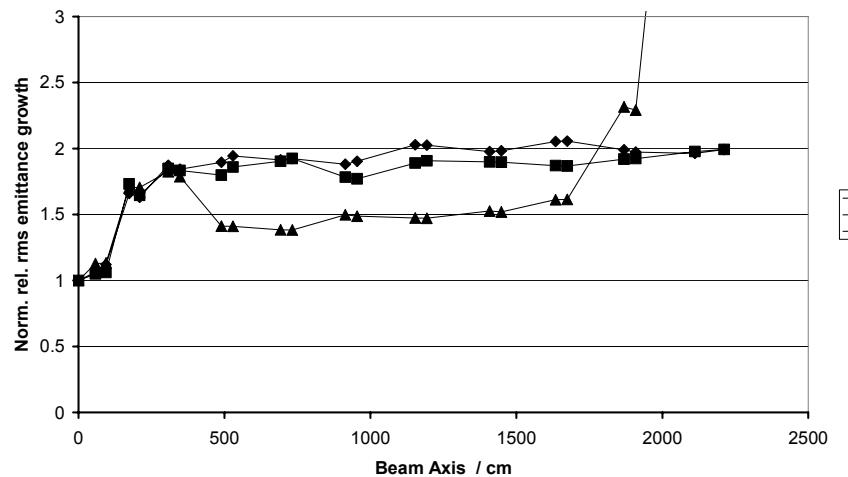
Case 1,
selected particles

Transmission : 100 %



Case 2,
all particles

Transmission : 99.9 %



Transition from the RFQ to the CH-DTL

The RFQ – DTL transition energy was meanwhile defined at **3 MeV**.
In this case the first CH-DTL is rather short, or quadrupole triplet lenses have to be included.

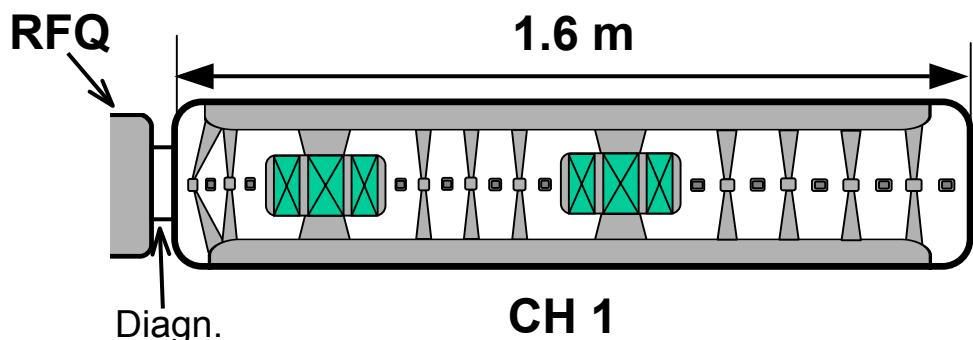
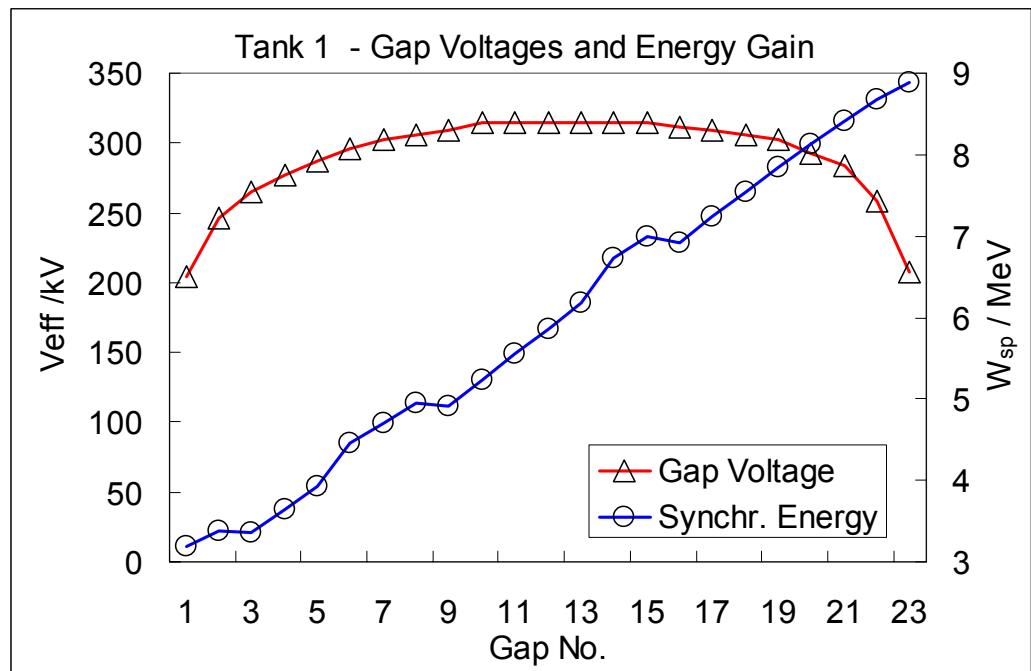
For RFQ-DTL beam matching two options are investigated in parallel :

- MEBT (buncher & quadrupole lens) ; injection into lens-free CH cavities.
- Direct RFQ-CH-DTL coupling (first CH-tank with two internal quadrupole lenses).

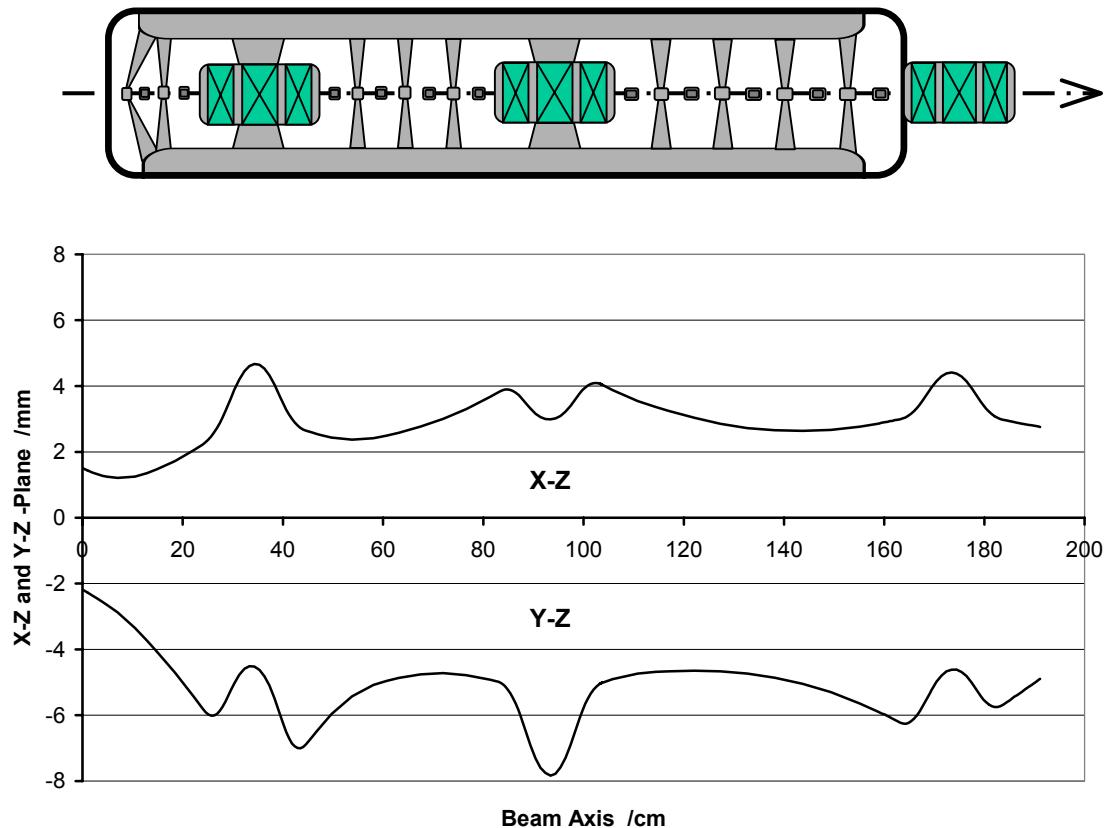
DTL Frontend Beam Dynamics Design (3-9 MeV)

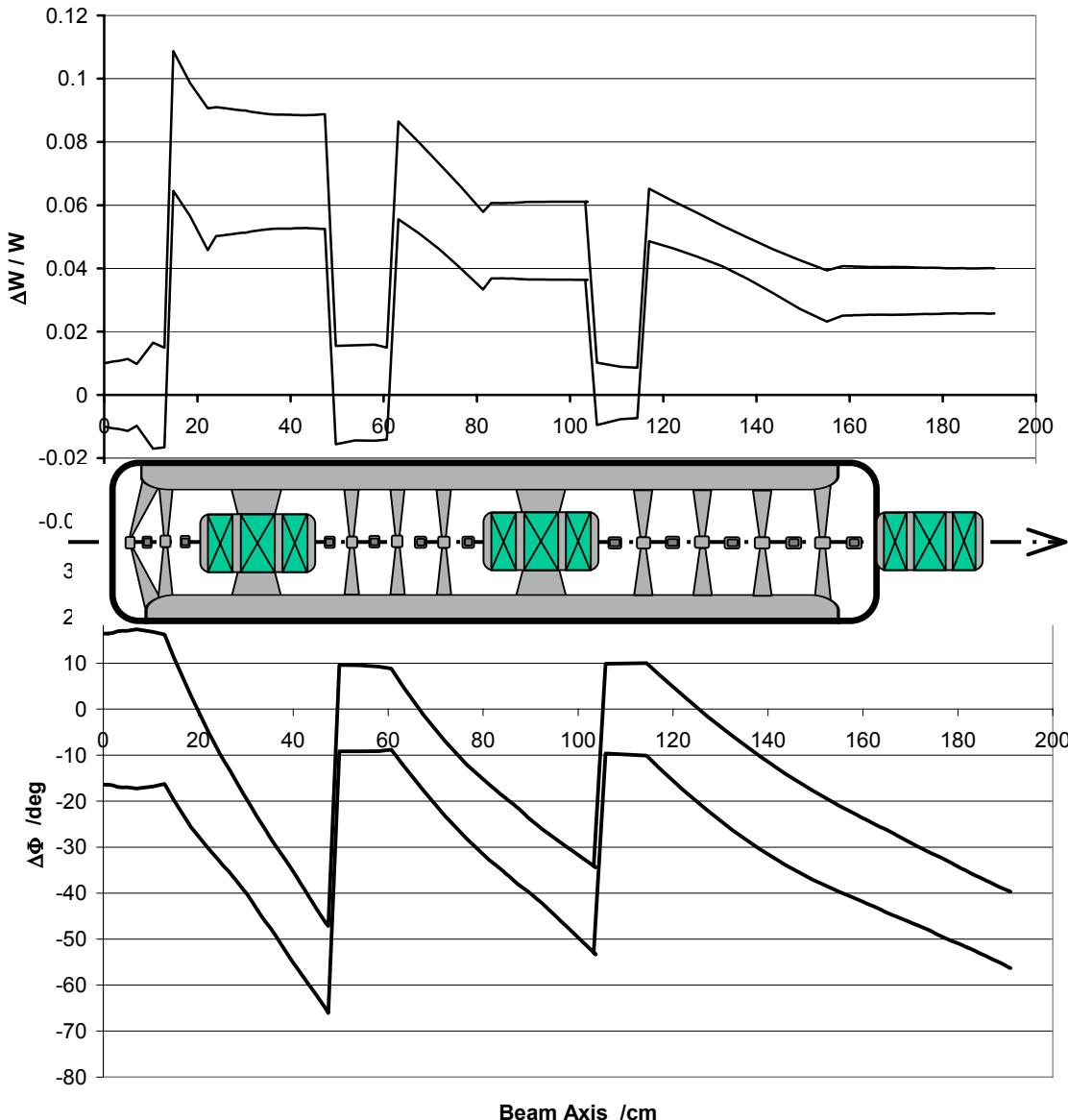
Direct Matching from RFQ to first DTL Tank

Gap	$U_{\text{eff}} / \text{MV}$	ϕ_s / deg	W_s / MeV		L / m
				3.02	
1	0.205	-35.0	3.18		0.035
2	0.246	-35.0	3.38		0.036
3	0.265	0.0	3.36		0.036
4	0.277	0.0	3.64		0.037
5	0.287	0.0	3.93		0.039
6	0.296	-35.0	4.45		0.041
7	0.302	-35.0	4.70		0.042
8	0.306	-35.0	4.95		0.044
9	0.309	0.0	4.92		0.043
10	0.315	0.0	5.23		0.045
11	0.315	0.0	5.55		0.046
12	0.315	0.0	5.86		0.047
13	0.315	0.0	6.18		0.049
14	0.315	-35.0	6.74		0.051
15	0.315	-35.0	6.99		0.052
16	0.312	0.0	6.92		0.051
17	0.309	0.0	7.23		0.053
18	0.306	0.0	7.54		0.054
19	0.302	0.0	7.84		0.055
20	0.293	0.0	8.13		0.056
21	0.284	0.0	8.42		0.057
22	0.258	0.0	8.68		0.058
23	0.208	0.0	8.88		0.058
				$L_{\text{gaps}} / \text{m} =$	1.1
$V_{\text{tot}} =$	6.7	MV		$L_{\text{tot}} / \text{m} =$	1.6



Transverse Beam Envelopes (95 % X-Z and Y-Z)



Longitudinal Beam Envelopes (95 %)

Status of the CH-DTL Beam Dynamics Design

- Further beam dynamics optimization is necessary, in order to reduce emittance growth.
Smaller RFQ output emittance values would be very helpful with respect to an optimized CH-DTL beam dynamics design.
- A direct matching into the first CH-DTL tank is feasible and helps reducing the total number of components and the overall linac length.
- However it is less flexible with respect to beam quality fluctuations.
In addition, the feasibility of a CH-DTL with integrated quadrupole lenses has to be investigated.

Deliverables ; Money ; Staff

- All design works are in time by now.

However : the time schedule for the construction and fabrication of the CH cold model and the prototype power cavity is quite tight, so that the cavity and beam dynamics design works have to be completed in time and as soon as possible.

- Money from EU (108733 € out of 145000 for the first 18 months) is ready to be transferred by Roy Aleksan to IAP-FU (initial contract problems – missing CA signature – have been overcome).
- The following PhD students are new within our team and working on CH structure and LORASR code development :

Name	email	Interest	Position
Höltermann,Holger	H.Hoeltermann@iap.uni-frankfurt.de	WP2,WP5	Non-Permanent staff (PhD-Student).
Dietrich,Jan	jan4711@gmx.net	WP2,WP5	Non-Permanent staff (PhD-Student).
Clemente,Gianluigi	Clemente@iap.uni-frankfurt.de	WP2,WP5	Non-Permanent staff (PhD-Student).
Dermati,Kaliopi	K.Dermati@gsi.de	WP2,WP3	GSI member (permanent PhD thesis at IAP).

Project TeamGSI

L. Groening
W. Barth

IAP

U. Ratzinger
R. Tiede
G. Clemente

GSI, IAP, Lanzhou

Z. Li

IAP Linac Group :

H. Liebermann
Y. Lu
H. Podlech
A. Sauer

IAP - LORASR code dev. :

J.Dietrich
H.Höltermann

Involvement of « IAP-FU » in CARE activity « HIPPI »			
Personnel			
Name	email	Interest « name of work package »	Position
Ratzinger,Ulrich	U.Ratzinger@iap.uni-frankfurt.de	WP2,WP3,WP5	Project leader
Tiede,Rudolf	tiede@iap.uni-frankfurt.de	WP2,WP5	Permanent staff (physicist) Responsible for WP2 and WI
Podlech,Holger	H.Podlech@iap.uni-frankfurt.de	WP2,WP3,WP5	Non-Permanent staff (physicist) Responsible for WP3
Liebermann,Holger	Liebermann@iap.uni-frankfurt.de	WP2,WP3	Non-Permanent staff (PhD-Student).
Sauer,Andreas	A.Sauer@iap.uni-frankfurt.de	WP3,WP5	Non-Permanent staff (post doctoral position).
Deitinghoff,Horst	deitinghoff@em.uni-frankfurt.de	WP2,WP3,WP5	Permanent staff (physicist)
Pozimski,Juergen	pozimski@iap.uni-frankfurt.de	WP2,WP5	Non-Permanent staff (post doctoral position).
Meusel,Oliver	O.Meusel@iap.uni-frankfurt.de	WP2,WP5	Non-Permanent staff (PhD-Student).
Mueller,Illja	Ilja.Mueller@iap.uni-frankfurt.de	WP2,WP3	Permanent staff (engineer)
Hausen,Guenter	Hausen@iap.uni-frankfurt.de	WP2,WP3	Permanent staff (technician)
Reploeg,Sven	-----	WP2,WP3	Permanent staff (technician)
Jaitner,Joachim	Jaitner@iap.uni-frankfurt.de	WP2,WP3	Permanent staff (technician)
Baensch,Daniel	D.Baensch@iap.uni-frankfurt.de	WP2,WP3	Permanent staff (technician)
New Staff :			
Höltermann,Holger	H.Hoeltermann@iap.uni-frankfurt.de	WP2,WP5	Non-Permanent staff (PhD-Student).
Dietrich,Jan	jan4711@gmx.net	WP2,WP5	Non-Permanent staff (PhD-Student).
Clemente,Gianluigi	Clemente@iap.uni-frankfurt.de	WP2,WP5	Non-Permanent staff (PhD-Student).
Dermati,Kalopi	K.Dermati@gsi.de	WP2,WP3	GSI member (permanent) PhD thesis at IAP.

Outlook / Conclusions

- A strong impact on the development of the room temperature CH-DTL at IAP Frankfurt University is given by the design of a dedicated proton injector into the synchrotron SIS18 at GSI, as well as by the HIPPI collaboration.
- Main tasks relevant to HIPPI WP 2 are:
 - Beam dynamics design of the CH-DTL-section (up to 70 MeV).
 - CH-DTL cavity development (cavity geometry, design and fabrication details).
 - Optimization of cavity shunt impedance.
 - All efforts should lead to the construction and power test of the CH-DTL tank power cavity, scheduled for 6.2006.
- The status of the design work on all topics mentioned above was presented. A lot of work is still ahead.

Thank you for your attention !